Enhancing the Educational Development of Individuals in Group Projects

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ABSTRACT

Group Design Built Test (DBT) projects are well established as an effective means of integrating a number of the engineering science elements of the curriculum in the context of the practical realization of the solution to a design problem. In professional practice these activities are typically carried out in teams. In order to prepare students for what they will be expected to do in industry many accrediting bodies, such as the Institution of Mechanical Engineers (IMechE), require that degree programs contain at least one group DBT project.

At Queen's University Belfast these projects typically involve students identifying a customer need and then developing a viable innovative solution to the point of a working prototype, and also developing an associated business plan for the product introduction. As such these projects provide an opportunity for personal development in all of the CDIO phases.

With the introduction of a new degree in Product Design and Development (PDD) in 2004, based on the CDIO standards and syllabus, a decision was made to introduce such group DBT projects from first year and to repeat these throughout years 2 and 3 with projects of increasing complexity and duration. What has become evident is that the learning strategies of first and third year students differ considerably and that the learning environment needs be controlled differently for the younger students in order to facilitate their educational development across a full range of skills and attributes to produce balanced learners who are able to contribute to all phases of a new product development process.

The objective of a professional group of designers is to maximize the output of the team by getting each member to concentrate on what they do best. In the educational environment such an approach does not help students develop the areas in which they are weakest. They tend to avoid tasks in favor of someone in the group who is more competent in a particular area and as a result individuals build on their inherent strengths and fail to develop their weaknesses. It is therefore important to construct a regime, particularly in first year, which enables development and focuses less on rewarding the final output and more on encouraging participation in all aspects of a project.

The paper discusses observations of running DBT projects in Stages 1, 2 and 3 over the first 4 years of the PDD degree and provides an analysis of the effectiveness of policies and procedures introduced to enhance the educational development of individuals within group DBT projects. Results and conclusions will be drawn from ongoing monitoring, questionnaires and student feedback which has been carried out as part of the evaluation of the new PDD pathway.

KEYWORDS

Design Built Test (DBT) projects, Skills development, Cognitive development, Personal Development Planning (PDP), Assessment, Curriculum planning

INTRODUCTION

The capstone project is a well established element of the final year of many engineering undergraduate programs. It typically aims to provide an opportunity for students to demonstrate the application of disciplinary knowledge in a realistic design, build and test (DBT) activity. These objectives are well aligned with the objective of a CDIO structured program, to prepare graduates for professional practice, but if the capstone is the first such experience of a group project then students are likely to be ill prepared for this major task. If in addition to this all assessment is terminal and summative then opportunities for development can easily be missed.

Many such as Perry [1] have suggested that cognitive development is a multi stage process. Perry contends that growth happens in major steps and as a response to challenges set just above their current level of ability. He also determined that stagnation in development can occur if the challenge represents too big a step. Culver et al [2] described freshman students as “immature novices with limited knowledge of the physical world” and in their study focussed on the mechanisms available to develop these students for professional practice by the time of graduation and in line with the ABET EC2000 requirements. As part of their assessment of student development they also emphasised the importance of timely formative assessment as part of an educational system which gets the students engaged with their own learning.

The psychologist Csikszentmihalyi [3] describes flow as a state of consciousness in which people are more engaged with and get greater satisfaction from the activities in which they are involved. In an educational context this relates to deep learning rather than surface learning and assists the individual in their ability to progress through the stages of cognitive development. Csikszentmihalyi also contends that this state can be controlled by ordering the information that enters the consciousness. Often referred to as the “+1 principle” this requires setting tasks of appropriate level, challenging but achievable and related to prior knowledge and skill levels. Often described as being between boredom, where no new learning occurs, and panic where survival strategies rather than deep learning dominate.

In their description of the CDIO approach to the development of student skills and attributes Armstrong and Niewoehner [4] recommended that the CDIO standard 5 requirement for an introductory course that incorporates design-build experiences followed by at least one further design-build exercise of a more advanced and demanding nature should be extended to include a project based course in every year of the program. They also suggested that projects should progressively include more lifecycle stages in each year and build towards a capstone that would cover conception, design, implementation and operation phases.

Bloom’s taxonomy of learning domains [5] categorises learning behaviour into 6 levels and provides descriptors and key words to assist in the design and assessment of the learning process. The taxonomy can be used as a guideline for defining tasks and assessment methods. The different levels can be used to indicate the expected performance level to the student at different stages in their program and also as a means of measuring the current level of assessed work.

Table 1: Bloom's Taxonomy of Learning Domains

Level	category or 'Level'	Behaviour Descriptions	'key words' (verbs which describe the activity to be measured at each level)
1	Knowledge	recall or recognise information	arrange, define, describe, label, list, memorise, recognise, relate, reproduce, select, state
2	Comprehension	understand meaning, re-state data in one's own words, interpret, extrapolate, translate	explain, reiterate, reword, critique, classify, summarise, illustrate, translate, review, report, discuss, re-write, estimate, interpret, theorise, paraphrase, reference, example
3	Application	use or apply knowledge, put theory into practice, use knowledge in response to real circumstances	use, apply, discover, manage, execute, solve, produce, implement, construct, change, prepare, conduct, perform, react, respond, role-play
4	Analysis	interpret elements, organizational principles, structure, construction, internal relationships; quality, reliability of individual components	analyse, break down, catalogue, compare, quantify, measure, test, examine, experiment, relate, graph, diagram, plot, extrapolate, value, divide
5	Synthesis (create/build)	develop new unique structures, systems, models, approaches, ideas; creative thinking, operations	develop, plan, build, create, design, organise, revise, formulate, propose, establish, assemble, integrate, re-arrange, modify
6	Evaluation	assess effectiveness of whole concepts, in relation to values, outputs, efficacy, viability; critical thinking, strategic comparison and review; judgement relating to external criteria	review, justify, assess, present a case for, defend, report on, investigate, direct, appraise, argue, project-manage

In the UK a set of specific learning outcomes for undergraduate programmes is defined in the UK-SPEC published by the Engineering Council UK, a royal chartered educational charity responsible for the UK register of Chartered Engineers. The Institution of Mechanical Engineers (IMechE) use this set of outcomes when examining a course for accreditation. There are 27 learning outcomes specified across 5 categories which cover both disciplinary knowledge and professional skills and attributes. Part of the IMechE accreditation process focuses on identifying where these learning outcomes are delivered in the modules of a degree program. A matrix is produced for all modules over all years of the degree to help identify any gaps or imbalances that occur. This approach can also be used as a tool for designing a new degree, as well as auditing existing programs, ensuring that the relevant learning outcomes of the CDIO syllabus, ABET or UK-SPEC are met.

DBT GROUP PROJECTS IN STAGES 1, 2 & 3

Running in parallel with the School of Mechanical and Aerospace Engineering's CDIO implementation plan at QUB, focused on adapting the existing Mechanical and Aerospace degrees to the CDIO principles and standards, has been the introduction of the new PDD program which accepted its first students in 2004. Designed from the outset to be CDIO compliant this program is structured to have an integrated curriculum with group DBT projects in each of the first 3 years. The learning outcomes from the associated module handbooks are shown in Table 2. These illustrate a progression in level with key words in the learning outcomes being drawn from Bloom's taxonomy.

The level of cognitive ability required in each project in the sequence increases over the 3 years and facilitates the development of the students by building on their knowledge, skills and experience while setting a task at each stage sufficient to challenge them, in line with the "+1 principle".

Table 2: Summary of Learning Outcomes of DBT Project Modules in Stages 1, 2 & 3 of the QUB PDD Undergraduate Program

Stage 1 - MEE1025 – Design Project1 (1 group project, 12 weeks duration)
• Use creative and lateral thinking tools and techniques in the creation of ideas and concepts for an innovative new product. • Perform market analysis to compare products of competitors. • Conduct product dissection to analyze existing products. • Apply critical thinking and problem solving techniques in the development of a new design. • Use sketching, rendering and CAD skills to illustrate design concepts. • Produce a technical report and presentation, referencing relevant sources. • Develop time management, project management and team working skills
Stage 2 - MEE2026 – Design and Prototyping Projects 2 (3 group projects, 8 weeks each)
• Develop design briefs into viable physical prototypes involving a number of assembled components. • Use a range of Rapid Prototyping and virtual prototyping hardware and software tools along with physical testing to iteratively revise design concepts to establish an optimal solution. • Utilize a number of tools and techniques introduced in the Stage 1 "Product Design Methods & Practice" module, further developing the skills required of professional product designers. • Plan and organize a project. • Run effective formal design review meetings. • Develop problem solving and effective decision making skills. • Refine time management and team working skills.
Stage 3 - MEE3052 – Project 3P (1 group project, 24 weeks duration)
To provide students with experience of working within a team on a realistic major project developing a product from the identification of a problem / customer need through concept development, product design specification, detailed design, prototyping and testing and finally to a plan for manufacture. To enable students to gain further appreciation of the potential applications and practical limitations of the technical knowledge they have acquired throughout their degree program. After successfully completing this module students should be able to: • Identify an unfulfilled customer need and assess the potential for a viable new product in the market. • Apply knowledge and understanding of a specialist subject and related elements of professional product design practice. • Collate information, analyze and solve a technical problem. • Design or develop a system, component or process and recognize opportunities for improvements in a design through review. • Utilize appropriate laboratory equipment, computer software and instrumentation, in order to accomplish the objectives of a project. • Communicate effectively the results of a project in oral presentations and written reports. • Design and plan a project and manage the time involved to complete all tasks to the respective deadlines. • Work and learn independently. • Work and communicate effectively as a member of a project team. • Critically review all aspects of the completed design build and test project

In stage 1 the project is typically well constrained and looks only to produce an updated or improved version of an existing design. The students are given the theme of the project and are asked to benchmark and critically analyse against competitor products. Sample products are provided for dissection and analysis. The assessment regime provides opportunities for the development of skills taught in other modules, such as sketching and CAD, to be evaluated. New designs with unique selling points are developed and first prototypes required to demonstrate functionality only are made, often from recycled materials or prototyping foam. Several milestones (submissions) are indicated from the outset and students follow a structured product development process schedule supplied by the tutor.

In stage 2 the projects are often more open ended and challenge the students to produce an innovative concept and analyse its viability as a commercial product. Examples design briefs have included devices to make bananas bought in a supermarket last longer at home before becoming over ripe and devices to cleanly remove the top of a boiled egg. There may not be a perfect solution to these problems but the process of conceiving, designing and implementing a solution remains valid. Students are assessed in large part on how they carry out this process. Working prototypes are required to be produced (often using rapid prototyping) and tested, the results analyzed and conclusions drawn. Students are given less instruction regarding milestones and have to organise their own project plan and the division of labour within the group. Formal design review meetings are scheduled and chaired by the course tutor for the first project but subsequently this becomes the responsibility of the group. Computer Aided analysis tools are introduced by demonstration only and self paced learning materials supplied to the groups to encourage independent learning.

In stage 3 students are required to identify a customer need for which there is currently no effective solution on the market and develop a viable design for this need. In addition they develop in parallel a business plan for the product and determine the most effective route to market. Designs are developed with full manufacturing considerations and prototypes produced in the School's engineering workshop. Testing is also required to be carried out in a more comprehensive manner. While the themes of the project usually overlap with areas in which they have received formal instruction the nature of these projects often requires an amount of self learning in order to fully understand the issues related to a viable solution in the particular field. Groups must organise themselves and call and run the formal design review meetings at which the supervisors attend as regular members under the chairmanship of an elected group leader.

Figure 1 shows the author's assessment of the target level of skills and attributes that can be developed by students successfully completing the DBT projects in the first 3 years of the PDD program. It is important to recognise that while these are objectives they do not necessarily relate to the levels attained by all students on the program. The vertical axis indicates the level of learning in relation to Bloom's taxonomy as defined in Table 1. Conception is lower in stage 1, for example, since the theme of the project is provided and the students only seek to develop incremental improvements to something which already exists (level 3 – application) while a much higher level of conception (level 6 – evaluation) is targeted in stage 3 where original and unique solutions to problems are sought. In all phases (C, D, I & O) a stepped development is mapped out from which learning outcomes are defined and from which tasks and assessment regimes are subsequently devised to deliver these outcomes. This approach is consistent with the constructive alignment model defined by Biggs [6] and provides clarity to the student between the tasks set and the assessment requirements. These DBT modules are the core of the integrated PDD curriculum and provide an opportunity for students to immediately apply the engineering science content of other modules in a design context.

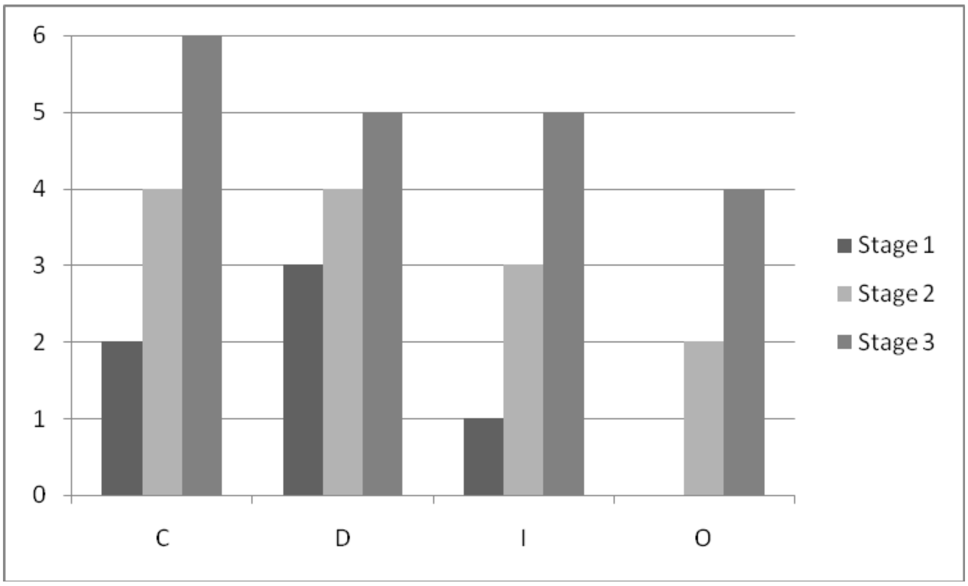

Figure 1 – Stepped Development Objectives of CDIO Skills and Attributes in PDD DBT Projects at QUB in Levels Defined by Bloom's Taxonomy of Learning Domains

ASSESSING THE INDIVIDUAL IN A GROUP

Most QUB engineering students arrive at university with limited or no experience of working or studying in a group. It is important to have a working system which first year students can see rewards those in a group who contribute more than average and also assigns lower grades to those who try to "take a free ride". From the outset it was decided that individual grades should be awarded rather than all members receive the same grade. While giving everyone in the group the same mark is certainly easier in terms of the effort required by the tutor it does not help build trust between the students and faculty. The alternative of having a rigorous, transparent and demonstrably fair marking scheme is not easily achieved but in the author's opinion if worth pursuing. Over the last 5 years the model for group marking has been revised taking into account feedback from students through module reviews, reflective critiques and questionnaires relating to the project organisation and assessment methods.

In all projects a combination of group and individual submissions are required with some variation between projects. In all cases a group technical report is produced using a standard template with Summary, Introduction, Theory, Market Analysis, Design Development, Testing, Results, Discussion, Conclusion, References and Bibliography sections. Group submissions would also typically include a presentation and associated prototype. Individual submissions may include project log books and reflective critiques as well as oral interviews.

Peer Assessment spreadsheets are used in all projects and are a mandatory requirement. The confidential peer assessment works on a zero mean basis with each student scoring themselves and all other members of the group in each of fifteen categories, which are aligned with the deliverables and learning outcomes of the particular project. Each row must add to zero and justifying comments must be entered in the right hand column for any rows with a non-zero value in any cell. Statements are provided describing the range of values between -2 and +2 which students can enter in each cell.

	Alan	Bertie	Clive	Darren	Eddie		
Technical Contributions	**Alda**	**Bassett**	**Clarke**	**Day**	**Edwards**	**TOTAL**	**Comments / Evidence**
Ability to apply technical knowledge (ergonomics, manufacturing processes, injection mould design)	0.5	0.0	0.5	-1.5	0.5	0.0	Darren did not apply any technical knowledge to the project. Alan, Clive and myself did most of the work.
Consideration of design requirements and constraints	0.0	0.0	0.0	0.0	0.0	0.0	
Sourcing of relevant technical information	0.5	0.0	-0.5	-0.5	0.5	0.0	I carried out all the research for the theory and the suitablity for injection mouldng. Alan researched on CES. Bertie used the resources of the library.
Contributed alternative design concepts	0.0	0.0	0.0	0.0	0.0	0.0	
Effectively troubleshoots problems and finds answers	0.0	0.0	0.0	0.0	0.0	0.0	
SUB TOTAL	**1.0**	**0.0**	**0.0**	**-2.0**	**1.0**	**0.0**	
Contributions to Deliverables	**Alda**	**Bassett**	**Clarke**	**Day**	**Edwards**		
Sketching, rendering and model making	0.0	0.0	0.0	0.0	0.0	0.0	
Geomagic	-0.5	-0.5	1.0	-0.5	0.5	0.0	Clive and I spent most time trying to figure out how to use geomagic. Clive used the geomagic on the final model we received.
Solidworks CAD	0.5	0.0	1.0	-2.0	0.5	0.0	darren did not do any of the CAD. Clive spent most time on the CAD. Bertie did try some of the CAD but it had to be edited.
CES & Moldflow	0.5	-1.0	0.5	-1.0	1.0	0.0	Alan and myself were the only people who looked at CES. Me and Clive spent most time looking at MoldFlow.
group report & user manual	1.0	-1.5	1.0	-1.5	1.0	0.0	Alan collated the report. Clive and I created the user manual.
SUB TOTAL	**1.5**	**-3.0**	**3.5**	**-5.0**	**3.0**	**0.0**	
Teamworking	**Alda**	**Bassett**	**Clarke**	**Day**	**Edwards**		
Effectively takes charge of tasks assigned	1.0	-0.5	-0.5	-1.0	1.0	0.0	I felt Alan and I had to organise most of the project, assigning tasks and checking what had and had not been done. Darren did not make any effort to move the project along.
Produces work on time	0.5	-0.5	0.0	-0.5	0.5	0.0	Darren and Bertie were the worst with handing work in on time. Clive did not do tasks for the dates he was supposed to.
Willing to take on fresh challenges	0.0	0.0	0.0	0.0	0.0	0.0	
Acted as a mentor to other group members and helped their skills development	0.0	0.0	0.0	0.0	0.0	0.0	
Communicates clearly with other members of the team	0.5	0.5	0.5	-2.0	0.5	0.0	Darren was poor at responding to emails or replying to comments on the forum.
SUB TOTAL	**2.0**	**-0.5**	**0.0**	**-3.5**	**2.0**	**0.0**	
GRAND TOTAL	**4.5**	**-3.5**	**3.5**	**-10.5**	**6.0**	**0.0**	
	Alda	**Bassett**	**Clarke**	**Day**	**Edwards**		

Figure 2 – Sample DBT Project Peer Assessment Spreadsheet

The spreadsheet values are not typically used in isolation to alter marks for individuals in group submissions but rather in combination with the supervisor's observations of individual contributions. The supervisors rate each individual in absolute terms on a weekly basis according to a metric which considers quality of contributions as well as quantity. The expected quantity of contributions is determined by the module size of the project. The observation scores come from performance at the formal design review meetings, conduct during timetabled classes and contribution to an online blog. To gain higher marks the contributions must clearly be of value to the project. The online blog also provides the opportunity for instant feedback by the supervisors which reassures students that the continual assessment is in fact being carried out continuously. The blog is archived automatically each day and also provides an audit trail should it be required at a later date to review individual contributions.

Students are advised at the start of a project that individual marks for group elements may be adjusted by as much at ± 25% about the group mean. Experience has shown that it is more likely for an individual to have their mark adjusted down by the full range due to lack of engagement than for an individual to have a significant adjustment upwards. In general it has been noted that less adjustment is required in stage 3 by which time the students are more fully engaged in the learning process.

PERSONAL DEVELOPMENT PLANNING

While the scope and progressive challenge of the DBT projects combined with the constructive alignment of the assessment regime provide a basis for each individual student to develop it cannot be assumed that this will occur in all cases. In order to develop to the higher levels in Bloom's taxonomy students will need to take responsibility for their own learning. The objective of the PDD degree is to produce balanced learners capable of making a significant contribution at all phases of a new product development. Entry surveys of learning style preferences over the last 5 years have shown however that many of the PDD students have a dominant preference and a minority have avoidance tendencies for particular types of task or activity. In group situations this typically results in the person who is most competent or comfortable at a particular task volunteering or being assigned to their area of perceived expertise. As a result individuals build on their inherent strengths and fail to develop their weaknesses, applying a strategic approach to completing the project.

A skills audit questionnaire linked to the Personal Development Planning (PDP) process within the School is used to highlight areas of strength and weakness. Students self assess their skills and abilities across a broad range of categories and record evidence to support their claims. They then meet with their personal tutor and after discussion come to an agreed rating for each item, usually lower than the student's first assessment. An action plan is then devised with the tutor who highlights opportunities associated with tasks and assignments where the required skills can be developed. Emphasis is placed on improving weak areas and in developing an attitude of continual professional development. The intention is that this process continues throughout their academic studies with diminishing input from the personal tutor as the student takes more responsibility for their own learning.

In support of this process the assessed tasks for the DBT projects are adjusted to provide ample opportunity for development in the areas where the cohort of students is weakest. To date the profile of each PDD year group has been characteristic and consistent with a dominant "hands on", practical preference and less enthusiasm for technical report writing, which consequently is an ever present part of the assessed elements of these modules. In order to encourage peer learning students are rewarded for mentoring team members in areas where they are more able. This is reinforced by having such "management skills" appear as items in the peer assessment spreadsheets. In the earlier stages the division of marks among the different tasks is also weighted towards the process of designing rather than concentrating on the final output. This is done to encourage individuals to develop the "softer" skills such as team working and project management.

FEEDBACK

Race [7] has identified 5 qualities and attributes which should be considered when seeking to provide effective feedback:

- **Timely** – early and often.
- **Intimate and individual** – it means more to the student if it is personalized.
- **Empowering –** need to take care when providing critical feedback not to demoralize.
- **Open doors not close them** - words such as 'weak' or 'poor' can cause an irretrievable breakdown in communication between tutor and student.
- **Manageable** - providing feedback to students can take up all your the time and energy

The structured series of DBT projects on the PDD degree seeks to meet all of these feedback standards. Among the methods employed are; anonymous peer comments from interim presentations, interim private peer assessment feedback, draft report comments and interim individual meetings to discuss supervisor's continual assessment grading. In these cases the feedback is formative and timely. In stage 2 when 3 projects run nose to tail in the same module there is also an opportunity for a full project debriefing to groups and individuals with an immediate opportunity to apply the lessons learned. In stage 3 the individual peer assessment feedback sessions concentrate on areas where contributions are significantly above or below the group average so that students can address the imbalance in the remaining weeks of the project. In all stages the project blog helps the supervisor identify who has contributed to the different tasks in the project and so the feedback can be personalised to assist with individual development. Before the introduction of the blog such individual and timely feedback could not be provided.

Throughout the development of the degree student opinions of the assessment and feedback regimes have been sought. Initially peer assessment was not linked directly to grades but student opinion was overwhelmingly in favour of changing the marking scheme so that their assessments were included. This change has been implemented but the module co-ordinator compares the supervisor and peer assessment grades to ensure that these are consistent and that no attempt has been made to “play the system”. If a significant mismatch occurs a second marker can be asked to examine the archive transcript and compare this to the supervisor’s weekly notes.

Table 3 shows the number of responses for a sample of questions from a larger questionnaire for the MEE3052 (Project 3P) module. From this it can be seen that peer assessment is viewed as a valuable process by the students and that it has a motivating and reflective influence on their learning.

Table 3: 0809 QUB Stage 3 PDD Attitudes of Peer Assessment

	STRONGLY AGREE	AGREE	NEUTRAL	DISAGREE	STRONGLY DISAGREE
Peer assessment is a valuable practice which helps me reflect on my own performance	7	11	2	2	0
I feel uncomfortable criticising the efforts of my peers, even anonymously	0	4	11	6	1
I would prefer that my individual marks and comments are made known and not just a group summary fed back to individuals	5	7	4	4	2
I am motivated to work harder knowing that my peers will be rating my contribution	3	10	8	0	1

Student feedback from module questionnaires suggests that the series of DBT projects have been well received with many positive comments identifying these projects as the place where the core skills required of the profession are developed, as was intended.

Teams from the first two cohorts through the PDD degree have had considerable success in external competitions. In 2007 a group of 4 students were one of 10 shortlisted finalists in the Enterprise Belfast 25k awards. In 2008 a group of 5 were runners up in the All Ireland Student Enterprise Awards. Of particular note is that the PDD students concerned were in stage 3 which is a year earlier than the other teams from the School who have previously been successful in these same competitions.

CONCLUSIONS

- Including group DBT projects in all stages of an engineering degree program can provide a staged development process for the skills and attributes required for professional practice.
- Bloom's taxonomy of learning domains can be used to define appropriate learning outcomes for the projects at each stage of such a staged development process.
- Including students' peer assessment in the marking scheme can help build confidence among the student body that individual's marks accurately reflect their contribution to the group.
- Timely formative feedback combined with a formal PDP process can be used to assist students in taking responsibility for their own learning.

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